

# Parameterizable Library Components for SAW Devices

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## ABSTRACT

To facilitate quick fabrication of Surface Acoustic Wave (SAW) sensors we have found it necessary to develop a library of parameterizable components. This library is the first module in our strategy towards a design tool that is integrated into existing Electronic Design Automation (EDA) tools. This library is similar to the standard cell libraries found in digital design packages. The library cells allow the user to input the design parameters which automatically generate a detailed layout of the SAW component. This paper presents the results of our development of parameterizable cells for an InterDigitated Transducer (IDT), reflector, SAW delay line, and both one and two port resonators.

**Keywords:** Design automation, modeling, simulation, software prototyping, surface acoustic waves microelectromechanical systems, MEMS.

## 1 INTRODUCTION

The lack of integrated design tools for SAW devices [1] has led us to develop tools that will enable design, modeling, simulation, analysis and automatic layout generation of Surface Acoustic Wave (SAW) devices. We chose to generate automated layouts to reduce design errors when transforming design parameters into a detailed design, to reduce the time necessary for the design process, and to create an interface between the layout editor and the simulation tool. The interface will allow integration of simulation and analysis tools with the layout editor.

## 2 PARAMETERIZABLE LIBRARY

Tool Control Language (Tcl) is a common scripting language [2]. Most commercial EDA tools include a provision for the creation and execution of macros using the Tcl language. The layout generator utilizes the Tcl language to create macros that automatically generate layouts of SAW devices. We created generators for the basic SAW IDT structures, reflectors, delay lines, and both one and two port resonators. Figure 1 is an example of the Tcl code that generates a simple SAW reflector structure.

```
#-----
proc Basic_Reflector { obj sname llayer dfinger_L
                    dfinger_W inum_fingers dbar_h } {
    global error_count

    set Length [expr ($inum_fingers*4*$dfinger_W
                    -$dfinger_W)]

    # Top comb fingers
    #=====
    # Finger origin of the first finger
    set FOx [expr 0]

    # Loops over all movable fingers
    for {set i 1} {$i <= $inum_fingers*2} {incr i} {

        # Draws the movable comb finger
        set finger [cat:rectangle -layer $llayer $FOx
                                [expr ($dbar_h)]
                                [expr ($FOx+$dfinger_W)]
                                [expr ($dbar_h+$dfinger_L)]]
        $obj addObject $finger

        # Next finger origin
        set FOx [expr $FOx + 2*$dfinger_W]
    }

    # Top Electrode
    #=====
    set rect [cat:rectangle -layer $llayer 0
                        [expr ($dbar_h+$dfinger_L)] $Length
                        [expr ((2*$dbar_h)+$dfinger_L)]]
    $obj addObject $rect

    # Bottom electrode
    #=====
    set rect [cat:rectangle -layer $llayer 0 0 $Length $dbar_h]
    $obj addObject $rect

    return
}
#-----
```

Figure 1. Example Tcl code for a SAW reflector.



Figure 2. Reflector layout from the Tcl code in Figure 1.

The code in Figure 1 draws a very simple structure that can be used to reflect surface acoustic waves. The structure has two bus bars or electrodes, one on the top and one on the bottom, and a number of fingers with spaces in between. Figure 2 shows the layout that is generated by the code in Figure 1.

Using the Tcl code similar to that of Figure 1 as a starting point we created a SAW delay line layout generator. We created code for an IDT then expanded it to include both transmit and receive IDTs. We added error checking to make sure the parameters input were within bounds. We then improved the code by adding a means of annotating the layout with the design parameters. We increased the flexibility by adding a way to change the X and Y offset of the device. A dialog box is automatically created for the input parameters from the Tcl code. We created a graphic in html and linked it to the layout generator using the help feature to assist in minimizing the ambiguity as to what the input variables represented. The graphic is located within the dialog box above the parameter entry area. These enhancements are all included in the layout generator we named Basic\_SAW\_Delay. The inputs for the Basic\_SAW\_Delay generator are; the length of the fingers, the amount of overlap between the fingers, the width of the fingers, number of finger pairs, the height of the bus bars, and the length of delay between the two SAW devices. Once the parameters have been entered into the dialogue box (Figure 3), a layout is generated. 3D models of the device and netlists which can be used to create fabrication masks can be created from the layout.

To demonstrate the capability of the layout generator we used the generator and the Basic\_SAW\_Delay component (Figure 3) to generate the layout of a SAW delay line with a wavelength of 60  $\mu\text{m}$ . The fingers are 15  $\mu\text{m}$  wide with 15  $\mu\text{m}$  wide spacing between them. The number of finger pairs per IDT is 10, and alternate fingers are attached to bus bars (electrodes) that are 50  $\mu\text{m}$  high. The aperture or finger overlap is 980  $\mu\text{m}$  out of the 1000  $\mu\text{m}$  finger height.

The delay length is input in multiples of the wavelength (seven in this case), but is calculated as  $7\lambda - 1/4\lambda$  or  $7 \cdot 60 - 60/4 = 405\text{ }\mu\text{m}$ , where  $\lambda$  is the wavelength. The delay length is the spacing between the fingers of the two separate IDTs. The subtraction of  $1/4\lambda$  is necessary to maintain the phase relationship between the first and second IDTs so no unwanted phase shifts occur. Figure 4 is the output of the layout generator using the parameters that are shown in Figure 3. The layout is automatically annotated with all of the device parameters except for the X and Y offset values. The text used for annotation utilizes a low flash count font and is created on the same layer as the IDT fingers. This self documentation feature is useful when placing numerous devices on a wafer with different parameters.

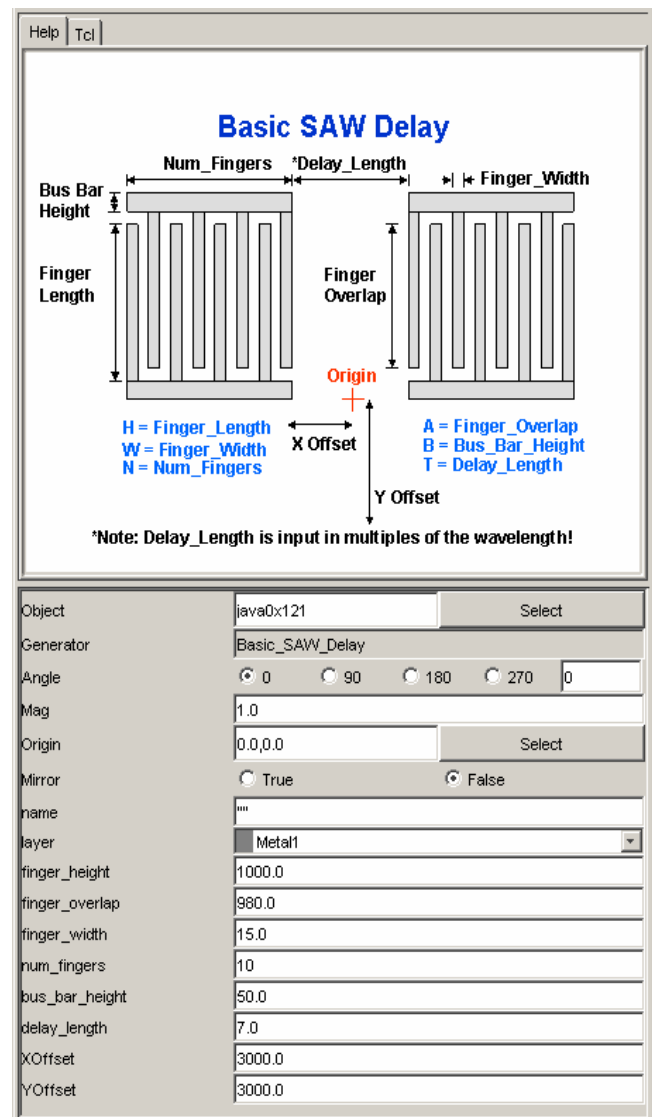


Figure 3. Layout Generator dialogue box. This box is where the parameters for the basic SAW delay line are input. We used the "Help" feature to include the graphic of the SAW delay device (above the parameter entry area).

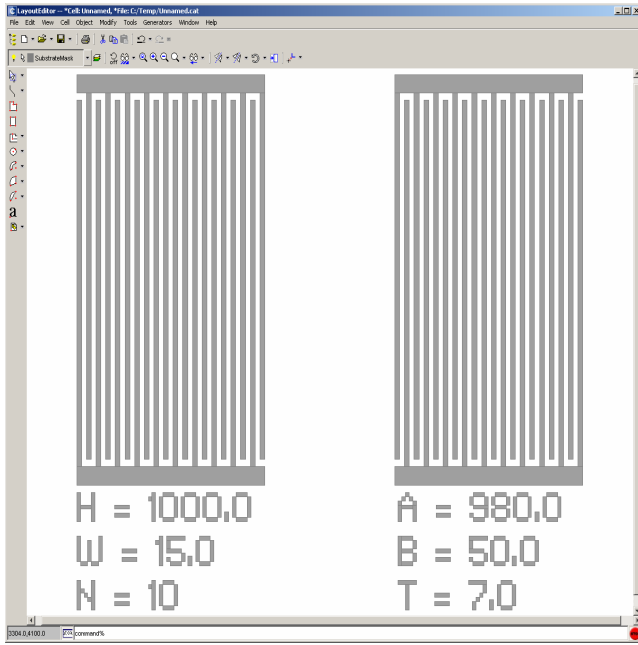


Figure 4. Layout of a basic SAW delay line. The device consists of two IDTs with finger heights of 1000  $\mu\text{m}$ , finger widths of 15  $\mu\text{m}$ , 10 finger pairs each with an aperture of 980  $\mu\text{m}$ . The bus bar heights are 50  $\mu\text{m}$ , and the delay between the two IDTs is 7 wavelengths. The device parameters are annotated using the same metal layer as the device.

We have also implemented one and two port SAW resonators [3]. The one port SAW resonator component consists of a single IDT in between two reflectors. The two port SAW resonator device consists of two IDTs

sandwiched between two reflectors. Figure 5 illustrates the two port SAW resonator component that we have developed. The aperture or finger overlap is 980  $\mu\text{m}$  out of the 1000  $\mu\text{m}$  finger height. The top and bottom electrodes or bus bars are 50  $\mu\text{m}$  high, and the fingers are 10  $\mu\text{m}$  wide with 10  $\mu\text{m}$  wide spacing between them. There are 20 finger pairs in each IDT and there are 50 fingers in each reflector. The internal cavity or spacing between the IDTs is one wavelength or 40  $\mu\text{m}$  wide. The external cavity or spacing between the IDT and the reflector is three wavelengths or 120  $\mu\text{m}$  wide.

### 3 IMPULSE RESPONSE MODEL

We used the Impulse Response method [4] to model the SAW device. This model is valid only for transducers where at least one of the two IDTs has equal weighting of fingers. Weighting or apodization of the fingers occurs when the overlap or aperture length is not constant [5]. This modeling technique does not take into account second order effects such as reflections, but it does model both the mechanical and electrical behavior of a SAW device and therefore it is sufficient for use as a first order model. The model calculates the frequency response, the loss of the system, the admittance, and the electrical parameters for circuit simulators. This model assumes a constant metallization ratio of 0.5, and uniform finger overlap or aperture. A simple circuit model (Figure 6) can be used to convey the basic elements of the Impulse Response Model. In the circuit model  $C_T$  is the total capacitance,  $B_a(f)$  is the acoustic susceptance, and  $G_a(f)$  is the radiation conductance.

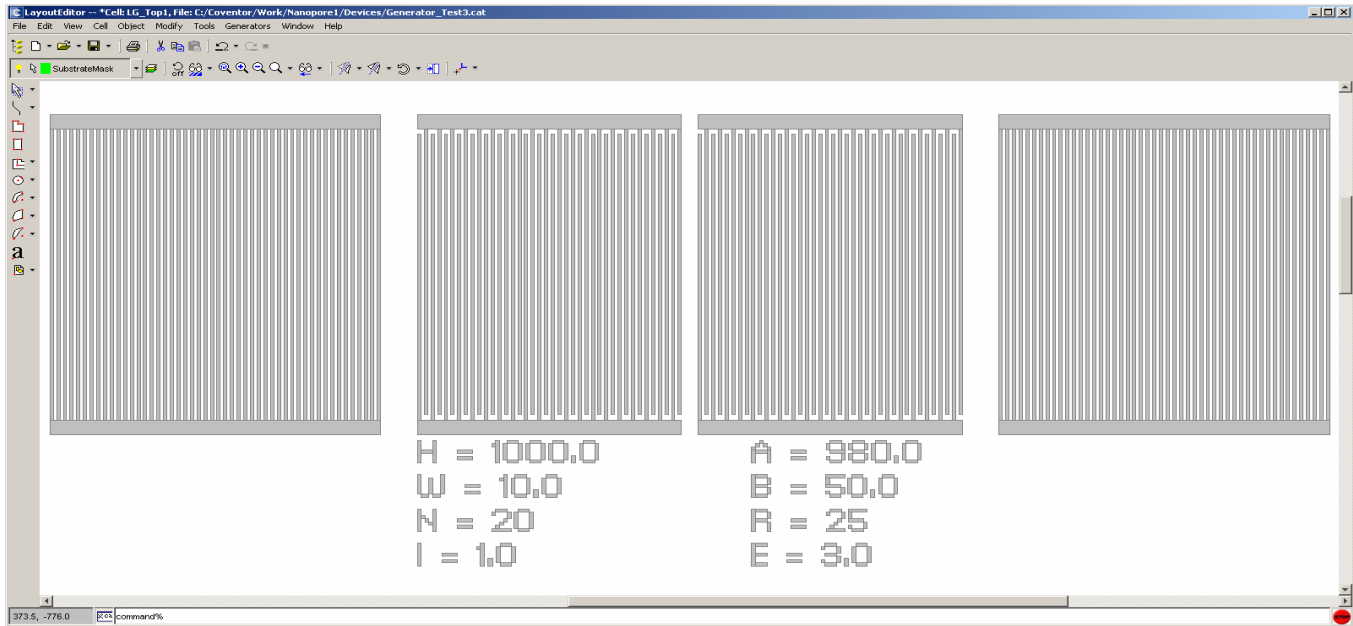


Figure 5. Layout of a two port SAW resonator. The device consists of two IDTs sandwiched between two reflectors.

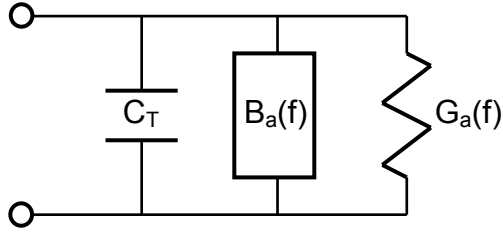


Figure 6. Circuit model used in the Impulse Response Modeling.  $C_T$  is the total capacitance,  $B_a(f)$  is the acoustic susceptance, and  $G_a(f)$  is the radiation conductance.

To begin the discussion on the Impulse Response model we first define the variable  $X$  as:

$$X = N_p \pi \frac{(f - f_0)}{f_0}, \quad (1)$$

where  $N_p$  is the number of finger pairs or  $\frac{1}{2}$  of the number of fingers per IDT,  $f$  is the frequency, and  $f_0$  is the synchronous frequency of the device. The frequency response from the Impulse Model for a single IDT is approximated by:

$$|H(f)| = 2k\sqrt{C_s f_0} N_p \frac{\sin(X)}{X}. \quad (2)$$

Where  $k$  is the coupling coefficient and  $C_s$  is the capacitance per finger pair and unit length. For this example we used the parameters from Figure 3 which yields a center frequency of 52.635 MHz. Figure 7 is a plot of the frequency response using an ST cut Quartz substrate. Note that the values are normalized by using the log equation:

$$H_n(f) = 20 \cdot \log \left( \left| \frac{H(f)}{H(f_0)} \right| \right). \quad (3)$$

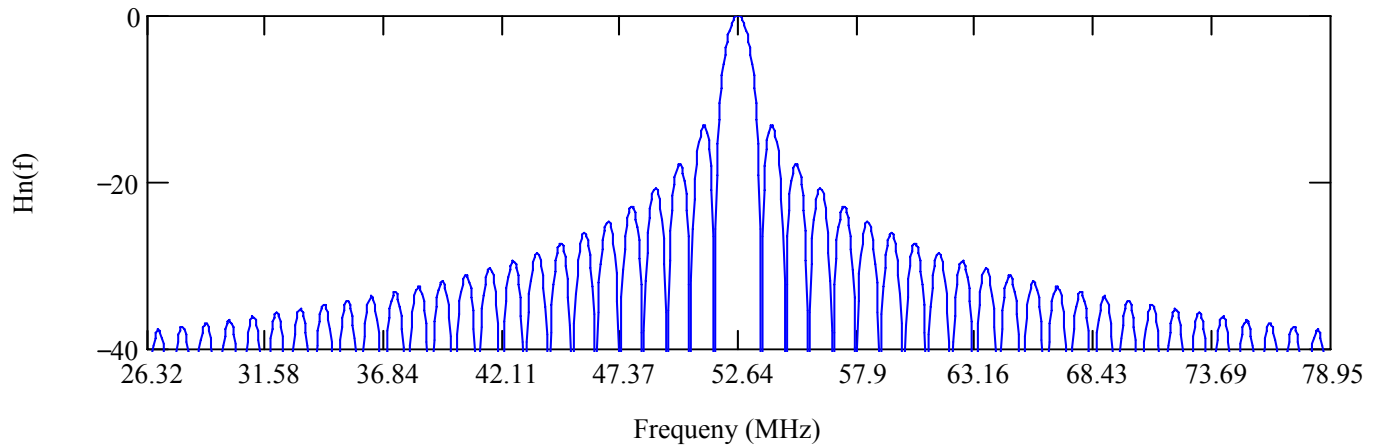


Figure 7. Frequency Response of the SAW Delay line on Quartz ST cut substrate with the values from Figures 3 & 4. The model uses first order approximations and is not optimized.

## 4 CONCLUSIONS

We have created a parameterizable component library of SAW devices. Currently the library includes cells for a single IDT, reflector, SAW delay line, and both one and two port resonators. These components enable us to generate automatic layouts for the SAW devices. We are currently developing modeling and analysis tools that will utilize the library. These tools will be integrated with existing EDA tools to take advantage of available FEA tools. We are currently implementing the Impulse Response Model for SAW devices. In The future we plan to add more complex SAW components to our library, such as apodized or aperture weighted devices.

## REFERENCES

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